

Comment on “ $^{187}\text{Re}(\gamma, n)$ cross section close to and above the neutron threshold”

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The work of Müller et al. [Phys. Rev. C **73**, 025804 (2006)] provides interesting experimental data on neutron emission by photodisintegration of ^{187}Re . However, the comparison to theory and the discussed implications for the Re/Os clock require considerable amendment.

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The recent paper by Müller, Kretschmer, Sonnabend, Zilges, and Galaviz [1] (hereafter referred to as MKSZG) presents measurements of the neutron emission from ^{187}Re induced by Bremsstrahlung photons. Derived cross sections are compared to predictions from two different Hauser-Feshbach models, NON-SMOKER [2, 3] and MOST [4, 5], showing good agreement. In the astrophysical application, the relevant quantity is the neutron capture on ^{186}Re . Due to the short half-life of ^{186}Re ($T_{1/2} = 3.7$ d), a direct measurement of the capture cross section is difficult. Therefore, MKSZG attempt to extract information on the reliability of the predictions from their data. While the data from the nice measurement are accurate and interesting, this latter interpretation and comparison to theory necessitates some remarks.

First, an apparent confusion in the comparison between the recommended value of Bao et al. [6] and the two models has to be rectified. In fact, the stellar enhancement factors and the MACS for $^{186}\text{Re}(n, \gamma)$ given in [6] are those of the NON-SMOKER code, as published in [2]. There are no experimental data included in [6] for this nucleus. The recommended value is derived by a renormalization of the NON-SMOKER value with a factor accounting for systematic errors in the NON-SMOKER calculations. The procedure is explained in detail in Bao et al. [6] (see Eqs. 1, 2 in that paper). The error bars are also derived in that procedure. Systematic errors may arise because both models, NON-SMOKER and MOST, are global models which do not include local data or parameterizations of the relevant nuclear properties but rather try to make predictions based on either microscopic models or global parameterizations. However, a comparison of the unrenormalized NON-SMOKER value of 1365 mb as quoted in [6] (it can also be extracted from [2, 7]) to the recommended value of 1550 ± 250 mb shows that there is no large systematic error for nuclei with neutron numbers around $N \simeq 111$, according to the applied procedure. The quoted error bar is a very conservative estimate. Nevertheless, the accuracy at this neutron number seems to be better than the average uncertainty of 30% found earlier [8].

Considering the above, the fact that the “MACS calculated with the updated NON-SMOKER code is close to the value” given in Bao et al. [6], as stated by MKSZG, is not surprising. However, the statement “Both models predict a (n, γ) cross section which is smaller

than the value recommended” in [6] (quotation from MKSZG) clearly is unjustified. Firstly, the “updated” NON-SMOKER value clearly lies within the error bar of the recommended value. Secondly, even if this were not the case, this would not allow to draw conclusions of the kind MKSZG present because the Bao et al. value is the same theoretical value but including corrections for systematic errors, based on the same theory. More accurately, a renormalization and an error bar of similar magnitude should be applied to the quoted values of NON-SMOKER and MOST when attempting a comparison to the Bao et al. value [6]. This would reveal that the NON-SMOKER and the Bao et al. value are actually the same (except for a 9% difference, see below).

Also the statement by MKSZG that the “disagreement between the two models may have its origin in the lack of precise nuclear data that enter into both models” is an inauspicious wording. As stated above, both models are global models which deliberately refrain from using local data. However, it has to be agreed that experimental data is needed, to test the global predictions and to improve the global parameterizations used in the calculations. This can only be achieved through a detailed comparison of theoretical and experimental results in test calculations.

One may notice that the “updated” NON-SMOKER MACS of 1485 mb given by MKSZG in their Table III (and incorrectly referenced as [3]; it should rather be “T. Rauscher, private communication”) is slightly larger than the unrenormalized value quoted in [6]. This is due to the fact that the calculation performed for MKSZG included E1, M1, and E2 photon transitions, whereas the older calculation [2, 3, 7] only included E1 and M1. The 9% difference shows that E2 transitions are not very important but contribute to the final cross section nevertheless.

MKSZG conclude that the “fact that both model predictions are in good agreement with our data but could not reduce the overproduction of ^{186}Os supports the idea that the adopted value of the $^{186}\text{Os}(n, \gamma)$ cross section is too small”. While the experiments at n_TOF and at FZK may indeed suggest this, a similar conclusion from the MKSZG data and comparison to the Hauser-Feshbach predictions is premature without a detailed study of the sensitivities of the predictions to the actually measured quantities. For example, the (γ, n) experiment on ^{187}Re in the ground state tests different neutron-

and γ -transitions than a neutron capture measurement on ^{186}Re . The photodisintegration includes a single E1 γ transition from the ground state of ^{187}Re , populating states with spins and parities of $3/2^-$, $5/2^-$, $7/2^-$. These states can then decay by neutron emission to ground and excited states in ^{186}Re . Thus, the properties of those low-lying states in ^{186}Re and the level density above the last considered excited state enter the calculated cross section. The situation is different for the (n,γ) direction. Assuming neutron capture on the ground state of ^{186}Re (the small stellar enhancement factor shows that capture on excited states contributes little), s-wave neutron transitions populate states in ^{187}Re with $J^\pi = 1/2^-, 3/2^-$. These states can then deexcite either by a single E1 transition to the ground state of ^{187}Re (from the $3/2^-$ state only) or via γ cascades involving different kinds of transitions. Thus, the properties of low-lying states and the level density in ^{187}Re enter the calculation of the cross section, as well as a contribution of E1 and M1 cascades (E2 transitions were not considered in the theoretical values quoted for the photodisintegration). Apparently, at best the (γ,n) experiment tests a subset of transitions relevant for (n,γ) plus some transitions which are of minor importance for the capture. This is true for most photon-induced experiments [9].

Further inspection suggests that the differences in the energy dependence of the (γ,n) cross section predicted in the two models are most likely due to the different treatment of the nuclear level density. As can be found in [7], 10 excited states in ^{186}Re up to an excitation energy of 314 keV are included in the calculation (the photodisintegration cross sections provided in [3] were computed with the same model and inputs as given in [7]). Both models, NON-SMOKER and MOST, include these states. Above 314 keV excitation energy, an average nuclear level density is invoked. The description of this level density is different in the two models, leading to a different number of possible transitions. Therefore, a difference in the calculated energy dependence in the two models is expected for photon energies of more than 314 keV above the (γ,n) threshold whereas a very similar behavior is to be expected below that energy. This is confirmed by Fig. 6 of MKSZG. This also underlines that not only neutron emission to the ground state of ^{186}Re is important but that neutron transitions to excited states also contribute. It should be kept in mind that the level density probed

here is the one in the odd-odd nucleus ^{186}Re and not the one in the odd-even ^{187}Re which is relevant for the neutron capture reaction.

Finally, Fig. 5 of MKSZG suggests that the energy dependence of the cross section differs from the measured one. The top panel of the figure shows that the energy dependence is compatible with s-wave neutron emission. (It is misleading here and in Fig. 6 of MKSZG to call it an “experimental cross section”. It is more appropriately called a “cross section derived under the assumption of pure s-wave neutron emission”.) Were the energy dependence of the models compatible with the experiment, it should be possible to fit the values shown in the lower two panels with a constant normalization factor f . However, the independence from the energy cut-off E_{max} of the integration in Eq. 6 of MKSZG is only destroyed by the normalization factors obtained for the two lowest cut-off energies. For these, the energy range close above the threshold S_n contributes significantly to the integral. Therefore these values of the normalization factors are very sensitive to the threshold region and the integration performed in the small energy interval just above the threshold. In addition to the quoted possibilities of deviations in that region, experimental uncertainties regarding the precise shape of the Bremsstrahlung spectra and numerical problems in the theoretical calculation, two further possible sources of deviations have to be mentioned. Close to channel openings, width fluctuations can occur in the cross section which have to be accounted for by a correction to the calculation [2]. It remains to be checked whether such fluctuations were treated appropriately. Secondly, the mesh used for the integration might have been simply too coarse as the determination of the renormalization factors for the theoretical models relies on the set of cross sections provided to MKSZG and the mesh on which the spectral energy distribution N_γ is evaluated. Considering these additional uncertainties, it is premature to conclude that the theoretical values show a different energy behavior than found in the experiment and to imply possible implications on the reliability of the related (n,γ) cross sections.

Summarizing, it has to be emphasized that an interesting, accurate measurement has been presented by MKSZG. This comment is intended as a correction of and an amendment to the discussion included in MKSZG.

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